NASA TECH BRIEF

NASA Pasadena Office

Microelectronic Fabrication of Superconducting Devices and Circuits

A proximity-effect superconducting device is a type of weak-link superconductor which exhibits Josephson-like effects, but operates on a different principle. The device is a thin-film superconductor with a short section that has been weakened in the sense that its pair density is lower than that of the rest of the film. It is expected that such devices can be used as detectors or sources of infrared and microwave radiation, as magnetometers, as voltage standards, and for voltage and current measurements, for electronic signal processing, and in digital circuitry.

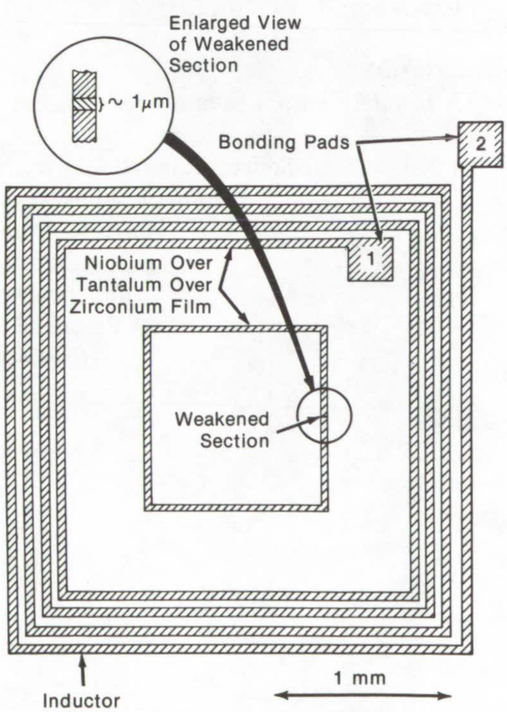

Figure 1. A Typical Design for a Superconducting Microcircuit

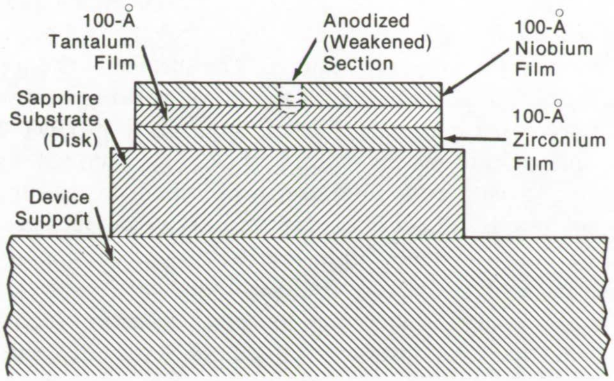

Figure 2. Example of Superconducting Films and Anodizations

To date, proximity-effect structures have been fabricated by a series of manual-processing steps. These methods require too much time and labor for large-scale production. To overcome the problem, a fabrication technology has been developed in which the manual processing is replaced with industrial microelectronic fabrication methods of the type used for semiconductor microcircuits. Operating prototype devices have already been made completely using this technology.

There are major differences between the present microcircuitry and this new projected form, such as the use of different materials, different processing techniques, and a different operating environment. For example, refractory superconducting films are used instead of silicon or germanium, anodization is used instead of doping to make active areas in the film, and the circuits operate at cryogenic temperatures instead of at room temperatures.

An example of the new technique is the following sequence of steps used to fabricate a batch of superconducting microcircuits containing proximity-effect structures. A typical microcircuit design is shown in Figure 1. The first step is to make a layered thin-film parent material as shown in Figure 2. A sapphire

(continued overleaf)

substrate [typically 1.5 in. (3.8 cm) in diameter by 10 to 20 mils (0.03 to 0.05 cm) thick] is sequentially coated with a base film of zirconium (or tungsten) about 100 Å thick followed by a middle film of tantalum also about 100 Å thick and a top film of niobium of the same thickness. These metals have superconducting critical temperatures of approximately 0.5, 4, and 9 K, respectively. The films are deposited in a single processing operation by the evaporative metal deposition technique under a high vacuum, on the order of 10^{-8} torr or higher. The sapphire wafer is heated to about 400° C prior to and during deposition.

The next step is to form the weakened sections needed for the proximity-effect structures. This is done in the following manner. The surface of the top metal film is covered with a positive working type of photoresist material, which is spun on to produce a uniform thin coating on the surface. The usual baking step to harden the photoresist is omitted; instead the coating is allowed to dry at room temperature. Baffling and yellow light are used as precautions to avoid undesired exposure to stray light.

The wafer is then placed in a mask aliner in which a mask has been installed. This mask is provided with multiple slot openings in the proper positions to produce the weakened sections (the slot openings in the masks are typically about 1 μm wide by about 100 μm long). The resist is then exposed and developed, and the wafer is then rinsed with deionized water and is blown dry with dry nitrogen gas.

As mentioned, the weakened sections are produced by anodizing. The anodizing process does not actually remove the metal but converts the exposed metal to its oxide. Anodizing is performed by applying a dc potential which is typically about 10 volts, for a period which is typically 0.1 second.

Following anodization, the photoresist is removed using an appropriate solvent, and the wafer is cleansed. A second photoresist is then applied. Additional masks to define the conductor leads and bonding pads are then placed in the mask aliner, alined with the first pattern; and the photoresist is exposed, developed in the appropriate developer, rinsed, and dried as before.

All of the metal of the films except that in the masked areas is then removed by plasma etching. Carbon tetrafluoride (CF_4) gas at a pressure of 0.7 torr with an RF power density of about 0.05 watts/cm^3 applied for a period of one-half hour produces a plasma which completely removes the exposed metal film areas. The remaining photoresist is removed with the appropriate solvent, and the wafer is cleansed, scribed, and broken into chips each of which contains a microcircuit. The chips are then mounted in integrated-circuit packages using epoxy cement. However, the cement is not baked but is allowed to cure at room temperature. Electrical connections between the pads on the chip and package are made with aluminum wire using ultrasonic bonding.

The sequence of steps given above is typical; variations of the procedure are possible.

Note:

Requests for further information may be directed to:

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NASA has decided not to apply for a patent.

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08 (Fabrication Technology)
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